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AEERL is managing three biomass-to-energy research, development, and demonstration projects. All three projects became a reality due to the initial funding from the DoD's Strategic Environmental Research and Development Program (SERDP) and the cooperation of the U.S. Government, state governments, and private industry. This paper provides the details and status of the projects.

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EMERGING SMALL SYSTEMS FOR POWER GENERATION FROM BIOMASS

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ABSTRACT

The U.S. Environmental Protection Agency's (EPA's) Air and Energy Engineering Research Laboratory (AEERL) is evaluating technologies fueled with biomass waste and/or energy crops for generation of electrical and thermal energy. Energy produced from biomass fuels mitigates greenhouse gases such as carbon dioxide and methane, and other air pollutants such as sulfur dioxide, nitrogen oxides, and air toxics. Advanced energy conversion technologies that are efficient, economically feasible, and environmentally sound are being targeted for development, demonstration, and eventually commercialization in both developed and developing countries.

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INTRODUCTION

Utilizing biomass as a fuel for power generation will eliminate sulfur dioxide (SO_2) emissions, produce zero net gain of carbon dioxide (CO_2), reduce air toxic emissions, and help solve waste disposal problems. Additional benefits from fueling a power generation system with biomass are savings from avoiding landfill tipping fees for disposal of biomass residues; savings from decreasing or eliminating the purchase of fossil fuels and/or electricity; and energy security from using indigenous biomass for fuel. These projects will provide the impetus needed for the development of equipment, design of systems, creation of markets, and promotion of exportable technologies.

One project is the demonstration of an energy conversion technology developed by ENERGEO, Inc., consisting of a fluid bed combustor fueled with biomass residues. Heat is transferred to compressed air via a recuperator, a convective exchanger, and a radiant exchanger. The hot compressed air is then expanded through a gas turbine to generate electricity. This project is expected to demonstrate the technical and economic feasibility, and to document the environmental impact of, a 200 kW unit at Sutton Lumber Company in Tennga, Georgia. Emissions and efficiency testing will be performed by independent experts.

Another project is the development of a biomass fueled integrated gasifier gas turbine (BIGGT) system by Cratech, Inc. The present phase of development includes a pressurized fluidized bed gasifier with hot gas cleanup that will produce a gas suitable for fueling a gas turbine engine. A pilot-scale system will be operated such that results can be compared with EPA-sponsored gasification tests performed by General Electric (GE) in 1991 [1]. The comparison will highlight differences between the GE fixed bed gasifier/cyclone system designed for coal and the Cratech fluidized bed gasifier/cyclone/filter system designed for biomass. The project should accelerate the development of the BIGGT technology for small systems. Successful development will produce increased efficiencies for small, biomass-residue-fueled power production systems.

Still another project is a demonstration of a biomass-to-energy technology on a military installation. The objective of this project is to demonstrate that an innovative energy conversion technology fueled with biomass is technically, economically, and environmentally feasible for DoD installations, industrial sites, and developed and developing countries. The approach is to identify a DoD host site, the partners, and the most viable technology, then design, build, and test the technology. The coordination between DoD and partners will be such that the design

of the project will be in the best interest of the DoD installation. The technical risks will be minimized by the proper selection of technology based on the available site, size of system, type of fuel, qualifications of operators, and lessons learned by all cooperators.

ENERGEO TECHNOLOGY DEMONSTRATION PROJECT

The first project discussed is the demonstration of the AGRIPOWER 200 technology developed by ENERGEO, Inc. of San Francisco, California. The AGRIPOWER 200 unit is scheduled to accumulate 8000 hours of operation over a period of 1 to 2 years at Sutton Lumber Company in Tennga, Georgia. The project is planned to demonstrate the technical and economic feasibility of the technology and document its environmental impact. Efficiency and emissions testing will be performed by independent experts. The objective of the program is to evaluate the operating and performance characteristics of the system using lumber wastes as fuel. Additional fuels may be included in the program at a later date. The sponsoring agencies have the option of extending the program for an additional year and another 8000 hours on line.

The AGRIPOWER 200 unit is an energy conversion technology fueled with biomass to produce electrical and heat energy. The system operates with an "open" Brayton cycle using a fluid bed combustor and several heat exchangers to heat compressed air which in turn drives a turbine generator (T/G) set. The T/G set and recuperator is packaged for this application by Alturdyne of San Diego, California. The balance of the system was designed by ENERGEO and fabricated by PMC Production in Sacramento, California. A turbine combustor included in the system is used for start-up and may be used to supplement the biomass fuel for maximum output and/or trim control of the turbine speed. The system also discharges clean hot air which can be used for cogeneration.

The process is shown schematically in Figure 1. There are two primary flow circuits in the process: a compressed air turbine circuit and a combustion circuit. The compressed air turbine circuit begins with the intake of ambient air by the compressor which is powered by direct connection to the turbine. The air is compressed to several atmospheres and exits through a recuperator which transfers heat from the turbine exhaust to the compressed air and improves the efficiency of the system. From the recuperator, the compressed air passes through a convective heat exchanger, recovering energy from the furnace flue gases. Then the compressed air goes to the furnace and receives additional energy via a radiant heat exchanger in the upper part of the furnace above the fluid bed. From the radiant exchanger the compressed air returns

to the turbine and expands through the turbine blades to power the compressor and the electrical generator. The turbine exhaust then passes through the recuperator and is either discharged to the atmosphere or utilized for cogeneration. Included as an integral part of the turbine is a fuel oil combustor which is used for "black" starts of the system.

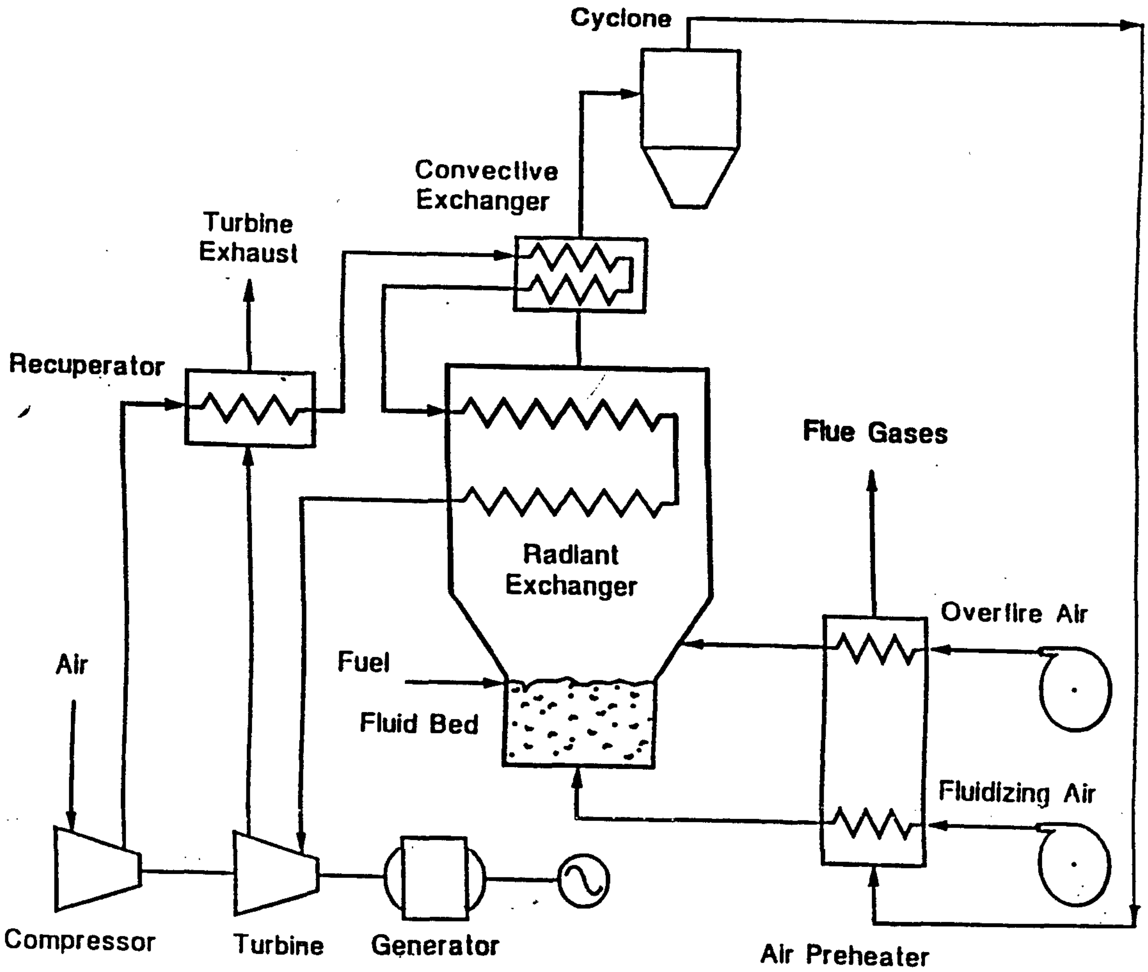

Figure 1 - ENERGEO'S AGRIPOWER PROCESS SCHEMATIC

The motors for the fuel feed screw conveyors and for all fans are variable speed as part of the system control. Feedback from the power output by the electrical generator and the inlet temperature to the turbine are used to regulate the amount of fuel supplied to the furnace. Key furnace temperatures are used to control the combustion air supply. Individual controllers are utilized for each principal control loop. The individual

controllers are supervised by a digital computer providing overall control of the system. If a computer fails, the individual controllers can operate independently. Under certain circumstances the computer can override the individual controllers and control the components directly. While the control system may appear complex, the interfaces with the AGRIPOWER unit operators are very simple. Start-up and shutdown procedures are programmed into the system computer. One of the issues to be resolved during the year of operation of the AGRIPOWER unit at Sutton Lumber is the best method for control of the turbine speed. Several possibilities exist to be evaluated.

Design specifications for the Sutton installation call for consumption of 278 kg/hr of fuel with a heating value of 12,385 kJ/kg. The net electrical output will be approximately 200 kW-hr/hr at the specified maximum capacity. This corresponds to a heat rate of 17,217 kJ/kW-hr. The performance goals call for a capacity factor of 95% which would yield an average heat rate of 18,123 kJ/kW-hr and a total cost (capital and operating expense) of \$0.06 for each kilowatt-hour of electricity generated. The initial capital cost of an AGRIPOWER system for general distribution would approximate \$2250/kW of installed electrical capacity. For cogeneration applications, the 8172 kg/hr of turbine exhaust leaving the recuperator still retains a temperature in excess of 260 °C. When this energy is used to displace fuel oil for drying, generating steam, or for other processes, significant savings can be obtained to the extent that the cost of generating electricity may be totally offset.

Biomass fuels sometimes contain small amounts of sulfur and nitrogen. The wood waste at Sutton Lumber has been reported to contain 0.04 wt% sulfur and 0.11 wt% nitrogen, both on a dry basis. The sulfur content yields SO_2 emissions of 0.12 kg/hr. The combustion temperatures within the AGRIPOWER combustor are low enough to avoid any significant fixation of nitrogen to produce thermal nitrogen oxides (NO_x), and essentially all of the NO_x emitted by the unit is anticipated from partial conversion of the fuel nitrogen. NO_x emissions are estimated at 0.18 kg/hr. The combustion in the furnace is well mixed with sufficient residence times to minimize carbon monoxide emissions which have been estimated to be 0.32 kg/hr. The ash content of the fuel is 1.0% on a dry basis, and most of the ash is collected in the cyclone. Particulate emissions in the flue gas exhausted from the cyclone are estimated at 0.2 kg/hr. The fuel is apparently free of any chloride content so hydrogen chloride emissions will be nil.

Direct combustion of biomass currently offers the simplest and most economical process for recovering the energy from biomass wastes. Throughout the developing areas of the world there exists

a huge potential demand for AGRIPOWER 200 units with some purchases contingent on successful operation of the demonstration unit. The waste heat from the system can be used to produce potable water and ice as well as for drying food and industrial products. Much of the worldwide demand for AGRIPOWER includes interest in cogeneration for water and ice. Future plans include design and fabrication of larger units which will meet some of the greater demands of industrialized applications.

The project is funded by EPA/AEERL, U.S. Department of Energy/Office of Solar Energy Conversion/Solar Thermal and Biomass Power, DoD/SERDP, Tennessee Valley Authority (TVA), ENERGEO, Inc., and Sutton Lumber Company.

CRATECH TECHNOLOGY DEVELOPMENT PROJECT

The second project discussed is the development of a biomass fueled integrated gasifier gas turbine (BIGGT) system by Cratech, Inc. of Tahoka, Texas. The goal of the project is to develop an economical, intermediate scale (1 to 20 MW electrical output) BIGGT system which can use a variety of biomass resources for fuel including high ash, slaggy fuels. The system is designed to produce a clean gas suitable for fueling a gas turbine. By designing and developing a biomass gasifier that can be incorporated into the gas turbine combustion system, Cratech will offer a system for generating electrical power as small as 1 MW with the efficiency of larger systems using current conversion technology. The system is being designed to use a variety of biomass resources for fuel. The improved efficiency and fuel flexibility of this small biomass fueled power plant technology would improve the economics for supplying power to rural areas worldwide.

Cratech is progressing on a 3-phase plan to develop a 0.907 metric ton per hour (tph) BIGGT system. The objectives of Phase 1 were to design and construct a biomass gasification system capable of operating under a pressure of 2 atm[1], determine the system's capability of producing a clean gas suitable for fueling a gas turbine engine, and collect information that would enable design improvements. Phase 1 is complete and included design, fabrication, and testing at a low pressure of 2 atm and a fuel feed rate of 0.453 metric tph with cotton gin trash. Gin trash was collected from a local cotton gin and required no further processing prior to gasification. A report is being prepared with the results of Phase 1. Phase 2 is underway and includes redesign

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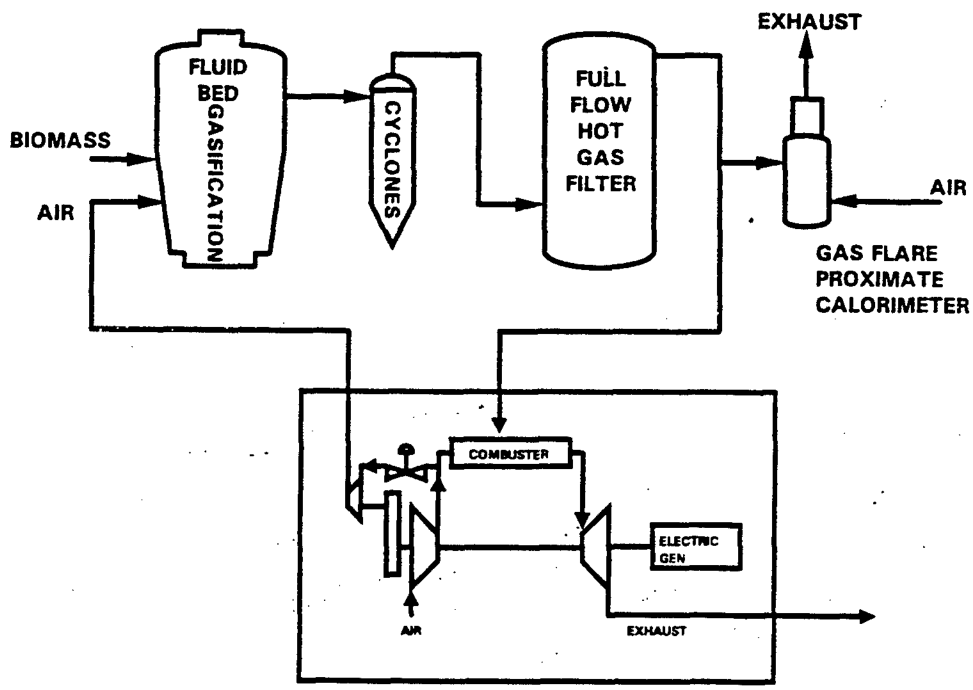
[1] 1 atm = 101.3 kPa

for gasification at a pressure of 10 atm, increasing the feed rate to 0.907 metric tph, fueling with wood chips, and evaluating the produced gas constituents and particulate content. Phase 3 will include integrating the gasifier with the gas turbine.

The power plant is based on a pressurized fluidized bed gasifier closely coupled with a Brayton cycle turbine engine. An advantage of a biomass integrated gasifier gas turbine power plant, compared with Rankine cycle power plants, is higher cycle efficiency. The process is shown schematically in Figure 2. The process begins when fuel is fed from a biomass bulk feeder to a pressure lock hopper system and then metered into the gasifier. Air is supplied to the gasifier from the turbine compressor. The fuel gas produced is first passed through a series of cyclones that separate out a majority of the char-ash particulate. The gas is then passed through a proprietary high temperature filter to remove the remainder of the particles. Heat remains in the gas with the use of a high temperature filter, thus improving system efficiency. Fuel gas then passes to the combustor in the gas turbine engine. The char-ash is removed, cooled, and stored for later use or disposal. The fluidized bed reactor was chosen because of its proven ability to handle high char-ash or severe slagging fuel.



GAS TURBINE ENGINE MODULE

Figure 2 - CRATECH SCHEMATIC

Some of the technologies which are being developed to make this concept feasible include feeding bulky biomass into a pressure vessel, accurate control of biomass feed rate, pressurized fluidized bed gasification, and high temperature gas filtration. This project should accelerate the development of the BIGGT technology for small systems.

There exists a sizable domestic and international market for this type of power plant. Wood milling and logging residues, bagasse, and rice hulls are the largest resources available worldwide for fueling biomass power plants. Users would include, but not be limited to, wood processing facilities, rice mills, vegetable oil mills, sugar mills, municipal power facilities, remote rural electric power facilities, textile mills, and ethanol plants [2].

The Phase 1 work was jointly funded by Cratech and the U.S. Department of Energy/Western Regional Biomass Energy Program (DOE/WRBEP). Phase 2 is jointly funded by EPA/AEERL, DoD/SERDP, DOE/WRBEP, TVA, and Cratech, Inc.

CAMP LEJEUNE DEMONSTRATION PROJECT

The third project discussed is to demonstrate a biomass-to-energy conversion technology, at a scale of approximately 1 MW of electrical output, at the Marine Corp's Camp Lejeune in North Carolina. Five initial sites on the Base are under consideration with all but one having an electrical substation in close proximity.

The biomass fuel for the demonstration is expected to be generated by activities on-site, in the community, and/or from dedicated feedstock supply systems. The base generates approximately 25,000 tons of mixed wood waste each year from base maintenance activities. This waste is currently being landfilled, and a waste recovery program is sought that will be of benefit to the Base. The waste will become the fuel for the demonstration and will be delivered in chipped or hogged fuel size to the demonstration site by Base operations.

The demonstration project plan emphasizes selection of a fuel conversion technology that is mature in its development (consisting of a substantial portion of off-the-shelf equipment) but also innovative. It is planned that the biomass conversion plant will represent a commercial option for electrical generation that will be transportable, modular, and relatively low-cost. This provides an option for waste wood utilization at industrial and small municipal sites, as well as many applications in developing nations.

The technology selection phase is in progress. Five factors

for evaluation are emphasized in the first stage of the selection phase. These factors are being considered for hypothetical plants at 1 MW and assume that the technology has progressed beyond prototype to a standard, commercial design. Therefore, factors include costs and risk to bring the technology to this state of maturity. The factors are:

1) Relative technology risk -- this includes the maturity of the technology, evidence from previous prototype demonstrations, requirements for modules that have received only limited evaluation or research, and known engineering limitations.
2) Innovation -- usually accompanied by high relative risk, innovation includes less mature technology with high potential for performance, cost, and environmental improvements.
3) Efficiency -- a measure of anticipated overall energy conversion performance, or heat rate. Evaluated on per-module and overall plant bases.
4) Cost -- includes both operating and investment costs relative to other processes compared for a base year and standard amortization.
5) Simplicity -- addresses estimated ease of installation and operation. Modularity and transportability will allow for varying fuel supplies and/or energy demand.

Wood energy-to-electricity conversion options have also been placed in five categories: 1) the conventional combustion boiler and steam turbine cycle (condensing), 2) combustion with expansion of gas products through a recuperating-type turbine (air turbine); and three options for utilizing low/medium Btu gas from a wood gasifier -- 3) gas turbine, 4) gas combustion in a boiler with a steam T/G set (condensing), and 5) reciprocating spark ignition or diesel engines.

A preliminary technology comparison is presented in Figure 3 using a rating scale of 1 to 5, where each category must receive its own (not a duplicate) ranking. When all factors are averaged, the combustion air turbine ranks best (at this scale of operation) because it is innovative but relatively low risk and can incur only moderate costs. This category is followed by 2) gasifier/engine, 3) combustion/steam turbine, 4) gasifier/gas turbine, and finally, 5) gasifier/steam turbine. Obviously, arguments can be made about the relative factors but, within project goals, the first evaluation is considered qualitatively accurate. Steam turbine cycles have been essentially eliminated because they are too conventional and require a water/steam cycle. Other options are still under consideration. Influences such as a breakthrough in gas cleanup technology that promotes gas turbine reliability, could

have a significant effect on the final evaluation.

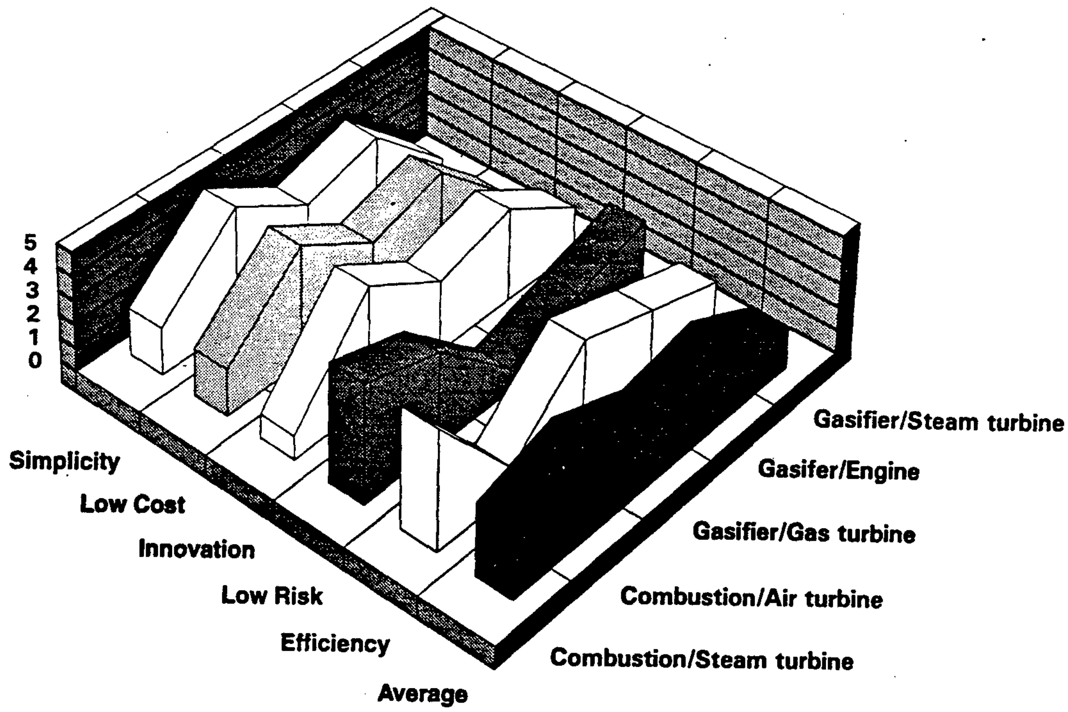


Figure 3 - PRELIMINARY TECHNOLOGY COMPARISON

Two other factors are also critical: 1) vendor reliability, track record, and project personnel, and 2) quoted cost of the installed prototype system (not the same as estimated commercial cost of standardized system). Final selection is expected in October.

Technology selection, final design, fabrication, and on-site installation are planned for the first two project years. Shake-down, testing, and final operation status will be achieved in the third and final year. Analysis and documentation of the project will be conducted, including equipment, procedures, operational performance, emissions and other environmental factors, and economics. The facility will remain on the site, operated by Base personnel, with connection into the local electrical grid.

Currently, the project is sponsored by EPA/AEERL, DoD/SERDP, North Carolina Department of Commerce's Energy Division, and Research Triangle Institute.

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